

Abstract

This performance report summarizes the research results obtained on NASA Ames Grant NAG 2-878 entitled "Investigations of Bacteriorhodopsin Films for Optical Signal Processing and Data Storage". Specifically we have performed research, at Texas Tech University, on applications of Bacteriorhodopsin films to both (1) dynamic spatial filtering and (2) holographic data storage. In addition, measurements of the noise properties of an acousto-optical matrix-vector multiplier built for NASA Ames by Photonic Systems Inc. were performed at NASA Ames' Photonics Laboratory. Our research on dynamic spatial filtering has, to date, resulted in a paper presented at a major optics conference. A journal paper is planned. A renewal proposal, entitled "Bacteriorhodopsin for Programmable Optical Interconnects", has recently been submitted to NASA Ames and is currently under review.

Introduction

Presented below are brief sections describing the research progress made under NASA Ames Grant NAG 2-878.

A. Dynamic Spatial Filtering with Bacteriorhodopsin Films

The photocycle exhibited by Bacteriorhodopsin (BR) film presents the opportunity to use this material as an optically addressed spatial light modulator. Figure 1 illustrates a simplified photocycle for Bacteriorhodopsin. Illumination of the film induces a rapid transition from the initial BR state through several intermediates to the M state, which (in our films) has a lifetime of approximately ten seconds while the film returns to the BR state through several intermediates by thermal relaxation. These two states exhibit largely non-overlapping absorption characteristics as shown in Figure 2. We have exploited this shift in absorption spectra and the corresponding change in intensity transmittance to use BR film as an optically addressed spatial light modulator in a dynamic spatial filtering system.

Figure 3 shows the basic spatial filtering scheme. When illuminated with collimated light, the first lens produces the spatial frequency spectrum of the input plane in the Fourier plane. A filter transfer function may be inserted to selectively pass or attenuate spatial frequency components as desired. The second lens images the filtered object onto the output plane. We

used BR film placed in the Fourier plane as an optically addressed spatial light modulator and wrote the desired filter transfer function onto the film.

We then implemented the dynamic spatial filtering system shown in Figure 4. This system used two optical paths from a single argon ion laser operating at 514 nm. The first path, controlled by mechanical Shutter 1, is used to write the filter transfer function to the BR film. The unexpanded beam is first passed through an acousto-optic (AO) cell which serves as a shutter only. Its purpose is to deflect the beam into the 2D Mirror Scanning System, effectively providing a "shutter" control more rapid than the mechanical Shutter 1. The 2D Mirror Scanning System is under computer control and positions the write beam to the desired location on the BR film. Lens L4 is positioned to focus the beam onto the BR film. In the second optical path, controlled by mechanical Shutter 2, the beam is expanded and collimated to illuminate the test object. We used a standard Air Force resolution test pattern as the input function. A neutral density filter was placed in the optical path to attenuate the object beam to an intensity that will not induce a significant transition of the BR film to the M state. The object was located in the front focal plane of Lens L1 and its Fourier transform appeared at the plane labeled FP. A second lens L2 was located to magnify the Fourier transform at the plane FP' with a magnification of approximately 4. We placed the BR film in this second Fourier plane. We set the object beam at an angle with respect to the filter pattern beam to allow the

simultaneous projection of the two beams without the filter pattern beam striking the output plane. Lens L3 was positioned to image the filtered test object onto the CCD camera where we either recorded the output image on a VCR or captured it with a frame grabber. The overall magnification of the imaging system was approximately 0.25.

Since the Air Force test chart consists of vertical and horizontal bars at various spatial frequencies, the Fourier distribution exhibits components only along the vertical and horizontal axes in the Fourier plane. We took advantage of this specific distribution and wrote filter transfer functions only to the horizontal and vertical axes of the Fourier plane. We wrote horizontal element only pass and vertical element only pass filters to the BR film. These filter transfer functions emphasize the vertical and horizontal stripes in the test object, respectively. We also wrote vertical element only and horizontal element only bandpass filters by writing a pair of "spots" to pass a particular spatial frequency. These filter transfer functions emphasize the horizontal or vertical bars of that particular spatial frequency. We demonstrated the dynamic nature of the system by alternately passing horizontal and vertical elements of the object's Fourier spectrum. The output alternately emphasized the vertical and horizontal bars of the test object.

A technique for writing continuous 2-D filter patterns is depicted in Figure 5, where the trajectory of the scan beam assumes that of a "tight spiral" pattern. The scan velocity

remains constant during the write process, and the light intensity is modulated by use of the acousto-optic cell shown in Figure 4. The scheme is superior to raster scanning, when using mirror-based scanning systems, as no sudden jerky motions are required of the mirror movements.

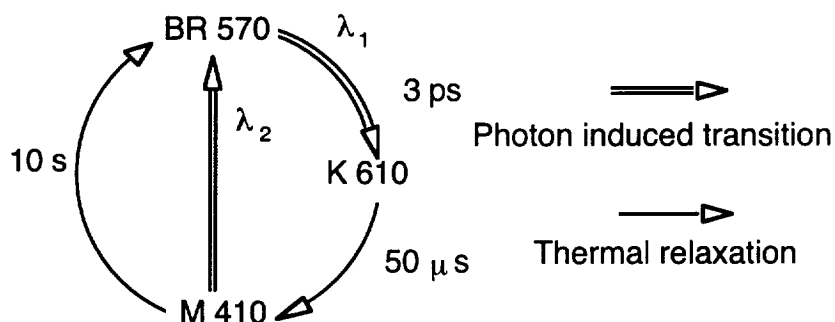


Figure 1: Simplified depiction of photocycle for Bacteriorhodopsin.

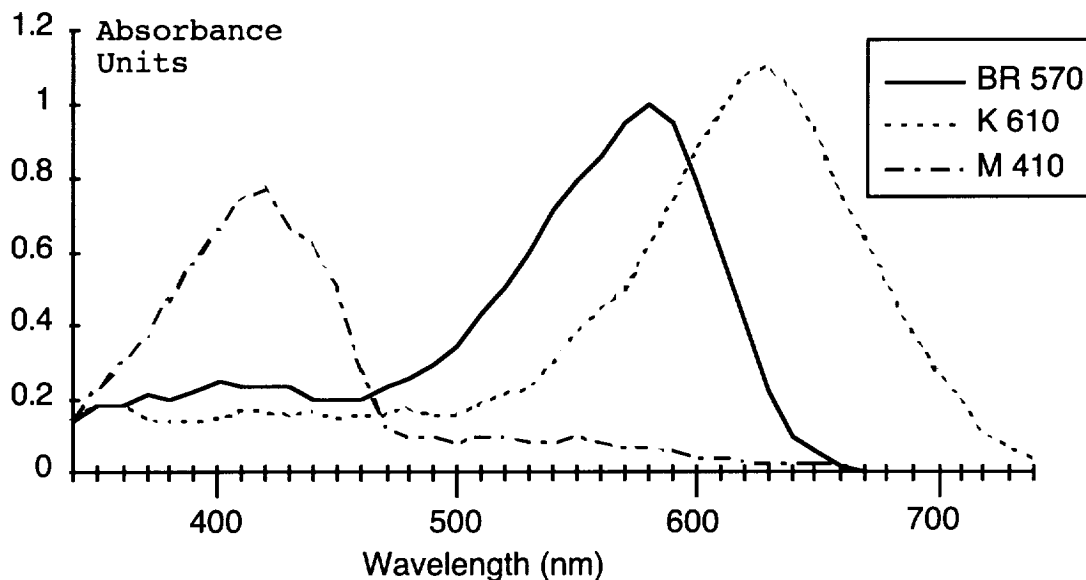


Figure 2: Absorption spectra of intermediate states in the photocycle of Bacteriorhodopsin.

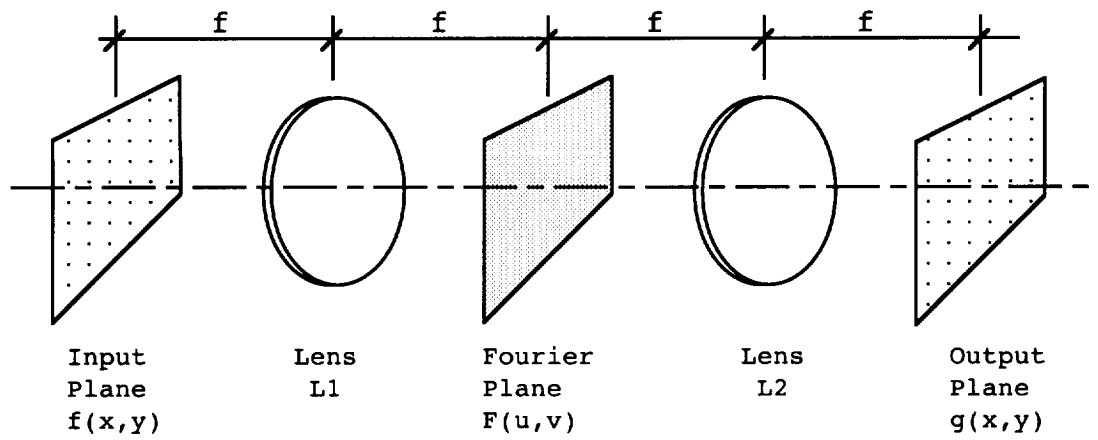


Figure 3: Basic spatial filtering system.

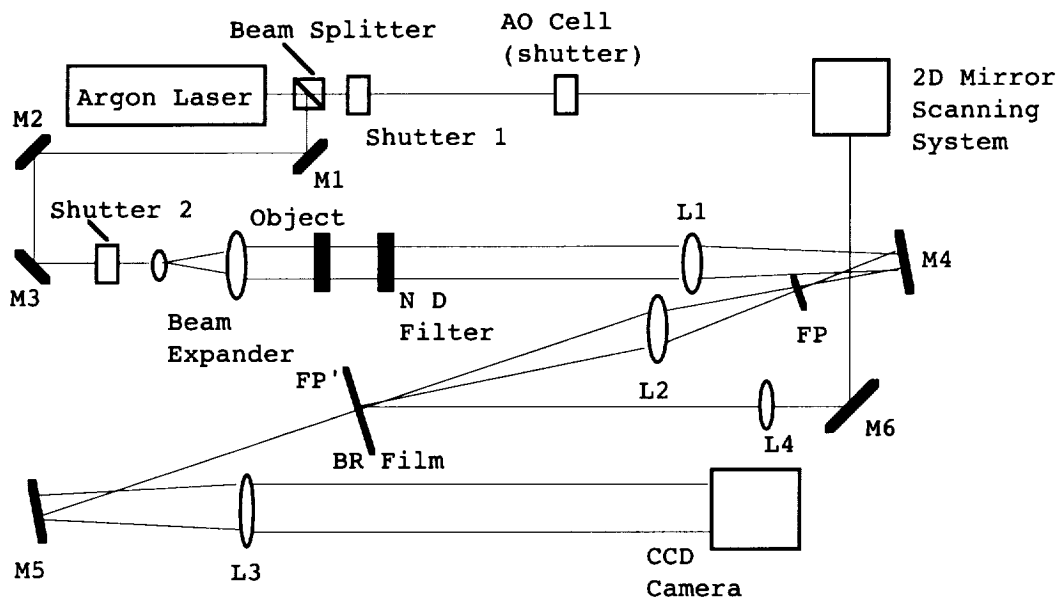
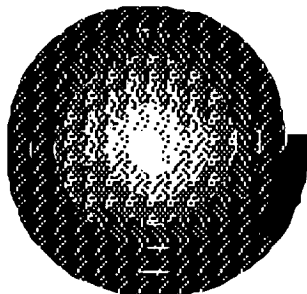


Figure 4: Dynamic spatial filtering system.



(2-D Gaussian)

Figure 5: Tight spiral technique for writing 2-D continuous filter patterns.

B. Holography for Information Storage in BR

A setup for recording holograms on BR is shown in Figure 6. A neutral density filter was employed in the reference beam for equalization of the reference and object beam intensities, so as to improve fringe contrast and diffraction efficiency. Initially, both Fresnel and Fourier transmission holograms were successfully recorded using SO-424 Kodak film and a HeNe laser. The recorded objects consisted of stencils forming the words "TTU" and "NASA". The lens shown in Figure 6 was used for Fourier transform holograms, and was simply removed from the system when recording Fresnel holograms. Fourier transform holograms must also employ a lens during reconstruction in order to reconstruct the original image.

Later attempts to record holograms using BR films, using an Ar⁺ laser, were only partially successful, resulting in poor diffraction efficiency. Our 5W argon laser is currently putting out only 200mW of power, and we suspect that the tube needs replacement. This limited power is marginal with regards to our efforts to write holograms in BR. It was also determined, by use of a Michelson interferometer, that the argon laser had a problem with vibrations. Although the setup was constructed on an air-suspended table, it was determined that the vibration problems may have stemmed from pressure fluctuations in the chilled water supply used to cool the argon ion laser. Consequently, the vibrations tended to "wash out" the

holographic fringe patterns. We are currently replacing the tube in our Ar+ laser, fixing leaks in our air-supported table and considering installing a pressure surge tank in the water line, in order to be able to successfully write holograms, so that properties such as crosstalk and readout signal-to-noise ratio can be evaluated. We hope to have the ability to write holograms before the end of the current grant.

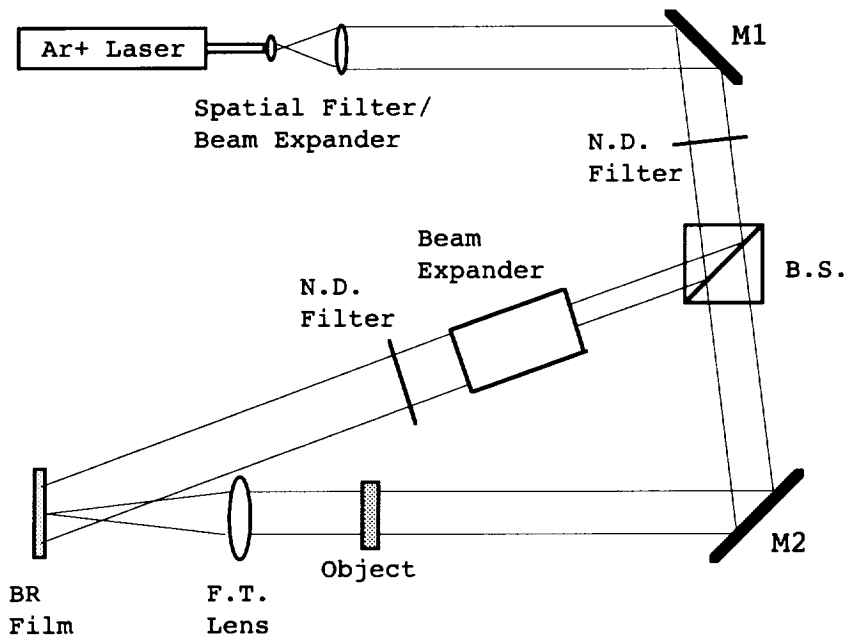


Figure 6: Setup for recording holograms for information storage.

C. Noise Measurements on Acousto-optical Matrix-Vector Multiplier Performed at NASA Ames Research Center

In late May and early June, 1994, Mr. Michael V. Morelli of the Optical Systems Laboratory traveled to NASA Ames and performed various measurements on an 8-channel input acousto-optical matrix-vector multiplier constructed, under contract to NASA Ames, by Photonic Systems Inc. These measurements were based on research techniques developed at Texas Tech University, by Mr. Morelli, as part of his AFOSR-funded Ph.D. dissertation research. The results of these measurements were communicated to Dr. Charles Gary, the technical program manager on this grant, and were used in a paper which he presented at an SPIE conference in San Diego, CA in July, 1994. An appendix in Mr. Morelli's Ph.D. dissertation will deal with these measurements, and a copy will be provided to Dr. Gary.

D. Papers Presented/Publications

A conference paper entitled "Dynamic Spatial Filtering with Bacteriorhodopsin Films " by S. Mark Storrs, John F. Walkup and David J. Mehrl was presented at the 1994 Annual Meeting of the Optical Society of America in Dallas, Texas in October, 1994. We plan to submit a journal paper to Optics Letters prior to the January 14, 1994 termination of the current grant.